

# Recycled Waste Glass Powder as a Partial Cement Replacement in Polymer-Modified Mortars

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**Abstract**—The aim of this study was to observe the behavior of polymer-modified cement mortars with regard to the use of a pozzolanic admixture. Polymer-modified mortars (PMMs) containing various types of waste glass (waste packing glass and fluorescent tube glass) were produced always with 20% of cement substituted with a pozzolanic-active material. Ethylene/vinyl acetate copolymer (EVA) was used for polymeric modification. The findings confirm the possibility of using the waste glass examined herein as a partial substitute for cement in the production of PMM, which contributes to the preservation of non-renewable raw material resources and to the efficiency of waste glass material reuse.

**Keywords**—Recycled waste glass, polymer-modified mortars, pozzolanic admixture.

## I. INTRODUCTION

THE construction industry is a major consumer of natural resources and a significant producer of waste [1]. In recent years, the sustainability of construction materials has become an important issue. At the same time, the recycling and reuse of waste is necessary from the viewpoint of environmental protection [2].

Utilization of solid waste in building materials seems to have considerable benefits for reducing waste disposal cost, decreasing greenhouse gas emission, conserving natural raw sources, meeting the new environment regulations and improving important properties of building materials [2], [4]. The use of 100% recycled glass as aggregate in architectural mortar is regarded as an environmentally friendly, cost-effective and attractive feature for application in construction due to the natural characteristic of glass (e.g. aesthetically pleasing appearance, impermeability, chemical resistance) [5]. The function of glass particulate will change from an inert mineral i.e. aggregate, to a reactive pozzolanic mineral that can be used as a cement replacement in concrete when the size of particles is reduced to a very fine powder – recycled glass powder (RGP) [6].

The alkali-silica reaction (ASR) is a critical factor limiting the incorporation of high content of sand glass and its wide application. Recycled glass contains the amorphous silica, which is susceptible to attack by alkaline environment and could depolymerize to form a monomer  $\text{Si}(\text{OH})_4$ . Formed monomer can further react with alkalis to form ASR gel, which is able to absorb water and expand inside the

microstructure of cement-based composite, generating internal tensile stress [3], [7]–[12]. Some researchers reported that 300  $\mu\text{m}$  particle size of glass sand is enough to suppress ASR expansion [10]. Other authors recommend the size range of 39–300  $\mu\text{m}$  to avoid ASR [11].

## II. MATERIALS AND PROPERTIES

In this study, the following types of waste glass available in the Czech Republic were used: Waste packing white glass (WG), waste packing brown glass (BG) and waste fluorescent tube glass (TG). All types of waste glass had to be milled before use. The particle size distribution of each RGP is shown in Figs. 1–3.

The cement used as a binder was Portland cement CEM I 42.5 R (Českomoravský cement a.s., factory in Mokrý). Crushed and milled limestone (OMYA Vápenná, a.s.) was used as aggregate. The mortars were modified with a redispersible polymer powder, specifically an EVA copolymer which was dosed at 2% of mass (Wacker Chemie AG). Table I shows basic mixture composition. PMMs were produced always with 20% of cement substituted with the prepared RGPs.

TABLE I  
COMPOSITION OF THE REFERENCE MIXTURE (RM)

Cement CEM I 42,5 R	250 g
Limestone (0–0.2 mm)	150 g
Limestone (0–0.2 mm)	150 g
Limestone (0–0.2 mm)	150 g
Limestone (0–0.2 mm)	300 g
Copolymer EVA	20 g
Water/Cement ratio	0.50

## III. SELECTED RESULTS AND DISCUSSION

The results of determining the pozzolanic activity, i.e. by means of measuring the amount of calcium hydroxide with which pozzolan-active substances can react, density, specific surface area and the content of selected oxides are listed in Table II.

Figs. 4, 5 show the results of compressive and flexural strength tests of the reference mixture and mixtures containing RGP at the age of 28 days, 90 days and 28 days + 25 freezing cycles. Figs. 4, 5 show the values of compressive and flexural strength of mixtures containing RGP are at the age of 90 days comparable to the strength of the reference mortar.

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TABLE II  
CHARACTERISTIC OF USED RGP

Type of pozzolan active glass	mg Ca(OH) <sub>2</sub> / 1 g of pozzolan	Density [g/cm <sup>3</sup> ]	Specific surface (Blain) [m <sup>2</sup> /g]	Content [%]				
				SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	Na <sub>2</sub> O+ K <sub>2</sub> O
Waste packing WG powder	574	0.663	0.188	71.2	0.6	0.2	8.8	13.2
Waste fluorescent TG powder	568	0.632	0.483	69.9	1.9	0.5	9.5	12.9
Waste packing BG powder	685	0.226	0.6257	71.1	2.5	0.2	4.6	17.9

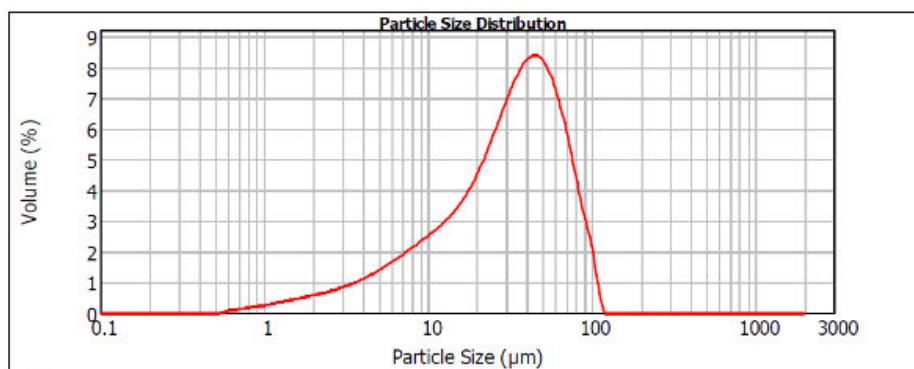


Fig. 1 Particle size distribution of waste packing WG powder

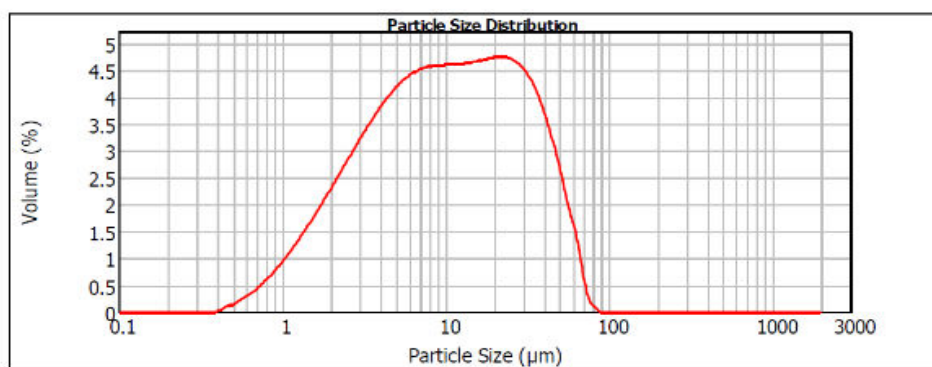


Fig. 2 Particle size distribution of waste fluorescent TG powder

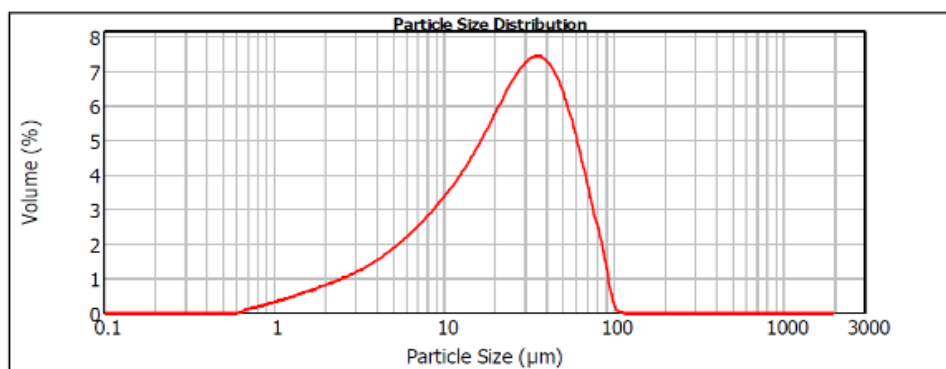


Fig. 3 Particle size distribution of waste packing brown powder

Fig. 6 shows the values of adhesion to concrete determined at the age of 28 days, 90 days and 28 days + 25 freezing cycles.

The application of waste fluorescent TG powder resulted in higher values of adhesion at the age of 28 days and 25 freezing cycles than in the case of the reference mixture.

The images, which were taken with a scanning electron

microscope, show the particles of recycled glass and C-S-H product formations. C-S-H phase growing from a grain of RGP can be seen in the mortar containing waste fluorescent TG powder (Fig. 9). The reference mortar (Fig. 7) exhibits a more frequent occurrence of ettringite compared with mortars containing RGP.

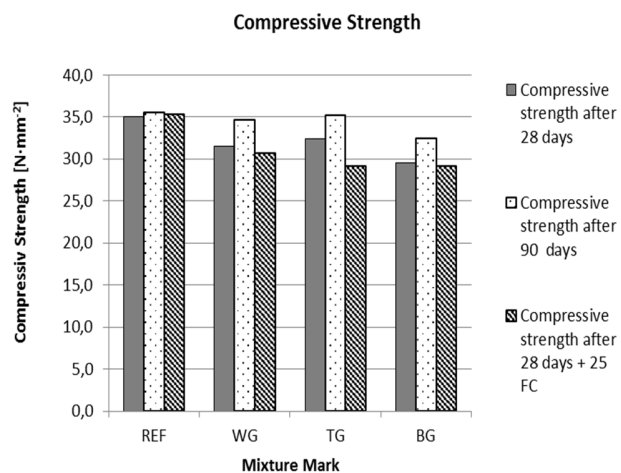


Fig. 4 Determination of compressive strength of mixtures with RGP

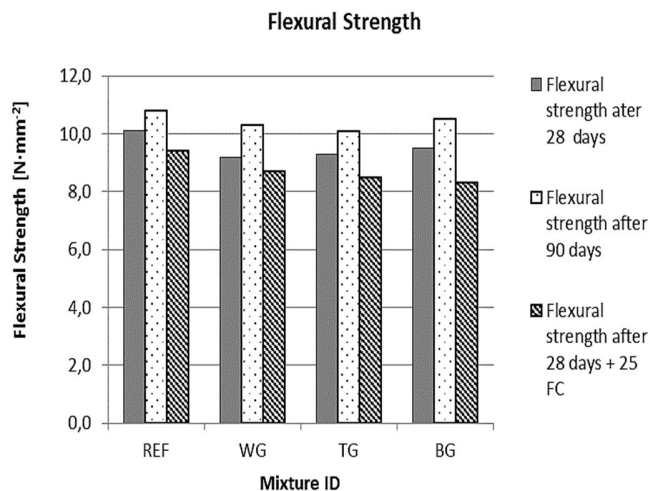


Fig. 5 Determination of flexural strength of mixtures with RGP

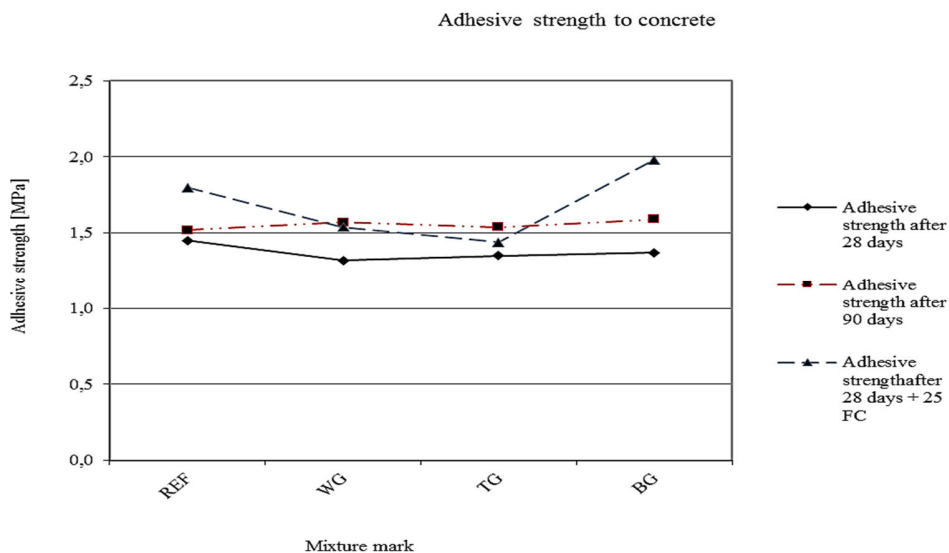


Fig. 6 Determination of adhesive strength of mixtures with RGP

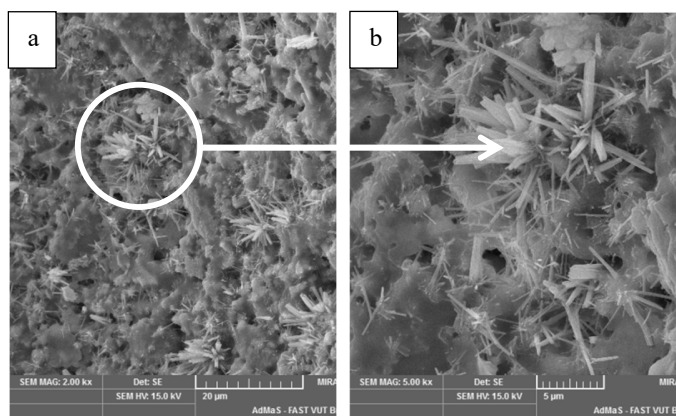


Fig. 7 An image of the reference mortar without an addition of RGP – (a) view of the structure of the matrix with ettringite needles visible at 2 000× magnification, (b) detail of the ettringite crystals at 5 000× magnification

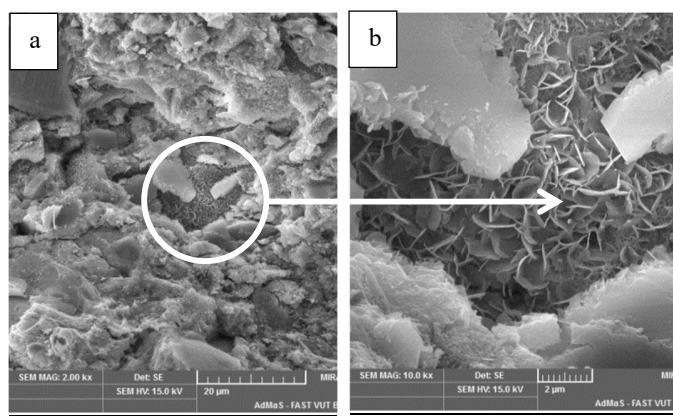


Fig. 8 Image of the mortar containing an addition of waste packing WG powder – (a) overview of the mortar with  $\text{CaCO}_3$  visible at 2 000× magnification, (b)  $\text{CaCO}_3$  as a product of carbonation, detail at 10 000× magnification

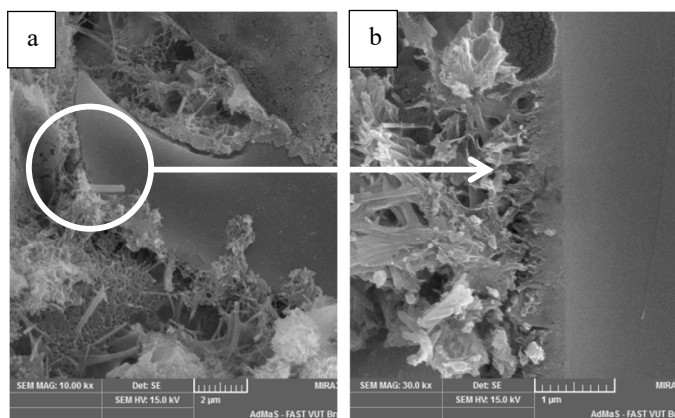


Fig. 9 Image of the mortar containing an addition of waste fluorescent TG powder – (a) part of a fluorescent TG particle with C-S-H phase formation visible at 10 000× magnification, (b) detail of C-S-H phase growing into the grain of fluorescent TG visible at 30 000× magnification

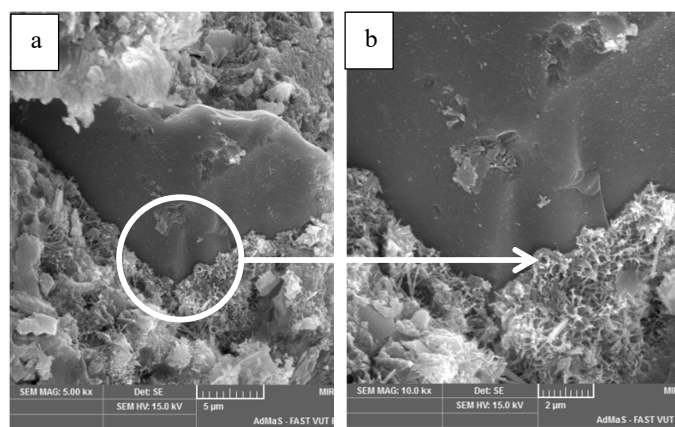


Fig. 10 Image of the mortar with an addition of waste packing brown powder – (a) angular grain of BG with C-S-H product formation at 5 000× magnification, (b) detail of the surface of the glass particle with C-S-H products at 10 000×

### III. SUMMARY

The goal of this research was to observe the properties of EVA copolymer-modified mortars containing selected pozzolanic admixtures. Given the large volume of waste glass found in the Czech Republic, where only 64–69% of it is recycled, the pozzolanic admixtures were powders made from three types of waste glass. RGP thus produced was used as a substitution for 20% of cement, the production of which is one of the greatest sources of CO<sub>2</sub> emissions.

The results of this research confirm that the selected types of waste glass possess sufficient pozzolanic reactivity and can thus be used as a partial cement substitute. The C-S-H products which were observed on the surface of glass particles contribute to improving the resistance to chemical attack and extending the service life of the cement composite. Using waste glass as a partial substitute of cement can be considered an eco-friendly solution that brings financial benefits since it contributes to preserving the environment and supports the

utilization of by-products.

### ACKNOWLEDGMENT

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